

# Marine macrophyte composition during summer, southwest and northeast monsoons in Verde Island, Batangas City, Batangas, Philippines

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## Abstract

Verde Island Passage is the world's center of the center of marine shore fish biodiversity, located in southwestern Luzon Island in the Philippines. The passage is named after Verde Island, which is located at its middle. Although the island is located within a key biodiversity area, studies on its marine macrophyte biodiversity are scant. The present study was conducted to determine the composition, distribution, and dominance of marine macrophytes, specifically seaweeds and seagrass, during the northeast monsoon, summer, and southwest monsoon in four coastal areas in Verde Island using the line transect-quadrat method. Results revealed 63 macrophyte species, of which 92% were seaweeds and 8% were seagrass. The majority of the seaweeds were green (41%), followed by red (35%) and brown (16%) seaweeds. In most sites, the brown seaweed *Padina* sp. was dominant during summer and cover decreased during both monsoons. The green seaweed *Neomeris annulata* was present in all sites and seasons. The differences in cover across sites may be due to substratum type and topography where a relatively wider intertidal zone with different substratum such as rocky and sandy to muddy provides complex habitat promoting higher macrophyte cover. Temporal differences in marine macrophyte composition were more pronounced in macroalgae-dominated sites than in the seagrass-dominated site. Several important seaweeds that could be studied as bioindicators were recorded, such as *Padina* sp., which registered high cover especially in sites near populated areas and backyard pig pens. *Ulva* spp., which are known to form green tide blooms, and *Caulerpa verticillata* were also noted and should be monitored. Some red seaweeds with potential for cultivation were observed (i.e., *Halymenia durvillei* and *Portieria hornemannii*). *Claudea* sp., an uncommon red seaweed with limited distribution in the Philippines, was recorded and needs verification. This study is the first extensive marine macrophyte assessment at the heart of the Verde Island Passage.

**Keywords:** biodiversity, bioindicator, eutrophication, microbenthic algae, seagrass, Verde Island Passage

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## Introduction

The Philippines is part of the most interesting marine areas in the world—the Coral Triangle. This marine hotspot also covers waters of Malaysia, Indonesia, Timor Leste, Papua New Guinea, and the Solomon Islands. Despite covering only 1.6% of the total ocean area, the Coral Triangle has the highest proportion of marine species diversity, constituting 76% of the coral species and 37% reef fish species in the world (Veron et al., 2011). According to Carpenter and Springer (2005), the Verde Island Passage (VIP), which lies within the Coral Triangle, is considered the world's center of the center of marine shore fish biodiversity. The passage is part of the

internal waters in the southwestern part of Luzon Island and bordered by the provinces of Batangas, Occidental and Oriental Mindoro, Romblon, and Marinduque. The VIP is threatened by impacts from increasing industrialization, human activities, tourism, and climate change. Worm et al. (2006) showed that biodiversity loss due to industrialization and human impacts negatively affects the ocean in terms of providing food, maintaining water quality, and recovering from perturbations. The VIP has been identified as a priority area for marine conservation and protection by the Philippine National Policy on Biological Diversity (Executive Order 578) and by Asaad et al. (2018).

However, only a few studies on its marine resources, even less so for seaweeds and seagrass (hereon referred to as marine macrophytes), have so far been carried out. Genito et al. (2009) reported eight seagrass species, including the dominant *Thalassia hemprichii* (Ehrenberg) Ascherson and *Cymodocea rotundata* Ascherson & Schweinfurth in Lubang and Looc Islands in Occidental Mindoro, with seagrass communities in these areas being threatened by slash-and-burn farming. VinceCruz-Abeledo et al. (2019) identified and compared seaweed species in Calatagan Bay, Batangas from 1985 to 2019 to link the possible effect of warming coastal waters with seaweed biodiversity change. They reported 10 new species records but did not observe 14 species that were previously reported from the area. However, their study was based on only one sampling conducted during the southwest monsoon.

Marine macrophytes provide many uses and services to humans and the marine ecosystem. Many coastal communities worldwide depend on seaweeds as part of their staple food and as source of livelihood through seaweed farming. Seaweeds are also used as organic fertilizer for plants and feeds for domesticated animals (Kumar & Sahoo, 2011; Makkar et al., 2015). Seaweeds may also serve as indicators of pollution, anthropogenic inputs (e.g., Schaffelke et al., 2005; Kim et al., 2014), and coastal productivity (Littler & Arnold, 1982). Marine macrophytes serve as food, shelter, and nursing grounds for marine fauna (Nagelkerken, 2009; Barbier et al., 2011; Cullen-Unsworth & Unsworth, 2013; Eggertsen et al., 2017; Tano et al., 2017). Seagrass and some seaweeds also play a role in sediment stabilization, carbon dioxide sequestration, and coastal protection (Barbier et al., 2011; Chung et al., 2011; Schmidt et al., 2011; Ondiviela et al., 2014 and references therein). In addition, seagrasses also function as nutrient filters (Short & Short 1984; Zarnoch et al., 2017) and reduce exposure of humans, fish, and invertebrates to bacterial pathogens (Lamb et al., 2017). Moreover, Stachowicz et al. (2008) showed that seaweed diversity increases standing seaweed cover, decreases the availability of free space for opportunistic species colonization, and increases recovery after disturbance. Thus,

assessing the biodiversity of marine macrophytes is crucial in furthering knowledge on the condition, status, and health of these important marine ecosystems. Additionally, macrophyte assessments may help in identifying seaweed species with potential commercial cultivation, which can be a possible livelihood for coastal communities.

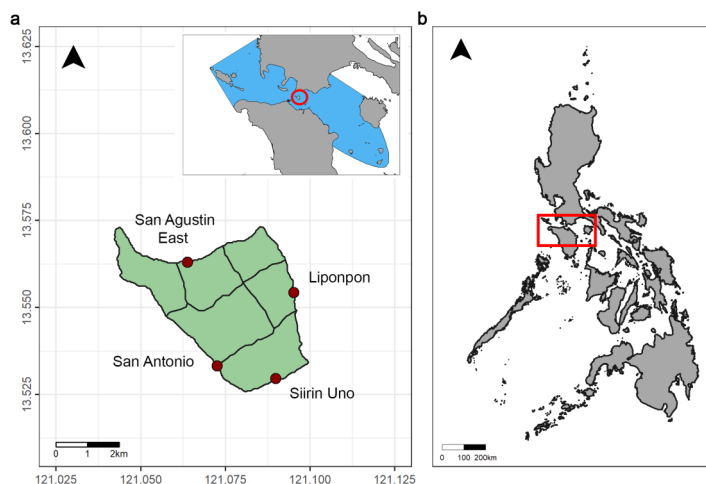
The VIP is named after Verde Island located at the heart of the passage. Although the island is part of a key biodiversity area, studies on its marine resources are scant and even less so for marine macrophytes. An initial assessment on the different marine shore ecosystems in Verde Island including marine macrophytes was conducted but is limited to only two sites and two seasons in 2018-2019 (Vacarizas et al., unpublished). The study showed that *Padina* sp. and *Halodule pinifolia* (Miki) Hartog predominated the intertidal areas, and the differences in marine macrophyte composition between sites may be attributed to differences in type of substrate. Stable anchorage provided by the rocky-coraline rubble substrate in the seaweed-dominated site may have allowed the site to support higher macrophyte diversity than the seagrass-dominated site. The objective of the present study was therefore to further assess the composition, distribution, dominance, and diversity of marine macrophytes in selected coastal areas in Verde Island.

## Materials and Methods

### Study sites

Four sites were selected around Verde Island (13° 32' 59" N, 121° 4' 15" E) based on their strategic locations to represent all sides of the island (i.e., San Agustin East in the north, Liponpon in the east, Siirin Uno in the south, and San Antonio in the west, Fig. 1). Siirin Uno has a relatively wide intertidal zone and gradual slope, with mostly sandy to muddy substrata dotted with rocky patches. This site was a seagrass-dominated area. San Agustin East, San Antonio, and Liponpon have a relatively narrow intertidal with generally rocky substratum with a slope that drops abruptly to the coral reef area. These three sites were seaweed-dominated. Moderate to strong water movement was observed in all sites. Depth ranged from 0.5 to 1.5 m in Siirin Uno and from 1.0 to 1.5 m in Liponpon, San Antonio, and San Agustin. See Supplementary Fig. S1 for the detailed physical features of these sampling sites.

Generally, the different physicochemical parameters fluctuated within close range in all sites across sampling periods. Seawater temperature ranged from 28 °C to 32 °C in Siirin Uno, 27 °C to 30 °C in San Agustin East and Liponpon and 28 °C to 30 °C in San Antonio. In all sites, salinity ranged from 32-33 psu, a pH of 8 (approximately) and dissolved oxygen ranged from 3 mg/L to 6 mg/L.



**Figure 1.** Map of Verde Island, Batangas City, Batangas, Philippines showing (a) the four coastal areas surveyed in San Agustin East, Liponpon, Siirin Uno, and San Antonio. The inset shows the location of the Verde Island Passage (highlighted in blue) where Verde Island is located (encircled in red). (b) Philippine map showing location of the passage.

#### Line transect-quadrat method

The line transect-quadrat method (Saito & Atobe, 1970) with modifications by Ganzon-Fortes (2011) was used to determine the community structure and distribution of seaweeds and seagrass in each sampling site. The sites were assessed in three sampling periods, during summer (April 23–26, 2019), the southwest monsoon (July 25–28, 2019), and northeast monsoon (December 11–14, 2019).

The distance of the macrophyte vegetation extending perpendicularly from the shore varies across sites to be approximately 50–60 m in Siirin Uno, 30–40 m in Liponpon, and 3–5 m in San Agustin East and San Antonio. Coral reef area was observed beyond the vegetation. Thus, transect lines were laid according to the topography of the sites. In Siirin Uno and Liponpon, three 50 and 30 m transect lines, respectively, were laid perpendicular to the shore at 50 m intervals. In San Antonio and San Agustin East, three 50 m transect lines were laid parallel to the shore at 30 m intervals. A 50 x 50 cm quadrat subdivided into 25 10 cm x 10 cm grids was used and placed every 5 m at the right side of the transect to avoid bias when scoring.

Species composition was determined by identifying all seaweed and seagrass species inside each quadrat. The cover ( $C$ , %) of each species was calculated by the summation of the total surface area covered by a species inside the quadrat using the following formula based on the index matrix of Ganzon-Fortes (2011) (Table 1).

$$C (\%) = (qn_6 \times 4) + (qn_5 \times 3) + (qn_4 \times 1.5) + (qn_3 \times 0.75) + (qn_2 \times 0.375) + (qn_1 \times 0.1875)$$

where  $qn$  is the total number of small squares with cover corresponding to index  $n$  described in the matrix. Cover was summed for each species in each site and thus may exceed 100%.

The dominant species (could be one or more) was determined by identifying species whose cover values constitute 50% or more of the total marine macrophyte cover in the area. Species contribution (%) refers to the proportion or contribution of each species in relation to the total macrophyte cover in the site. Shannon's Diversity Index ( $H$ ) was calculated using the formula  $H = - \sum ((n_i/N) \ln(n_i/N))$ , where  $n_i$  is the total cover of individual species and  $N$  is the total cover of all individual species.

#### Physicochemical characterization

The temperature ( $^{\circ}\text{C}$ ), salinity (psu), pH, and dissolved oxygen (mg/L) in each site were measured using a handheld multiparameter probe meter (YSI, Yellow Spring, Ohio, USA) during each sampling period.

#### Statistical analysis

Non-metric multidimensional scaling (NMDS) and similarity profile (SIMPROF) analysis were done to determine similarity and significant similarity ( $p < 0.05$ ), respectively, in the total cover of the marine macrophytes among sites in each sampling period. Similarity of percentage (SIMPER) was done to assess the species contributing to the dissimilarity between sites for each sampling period. All statistical tests were conducted using R software (version 4.0.2, R Core Team, Vienna, Austria).

## Results and Discussion

#### Species composition and diversity

A total of 63 marine macrophytes were identified in the island, comprising 41% green seaweeds, 35% red seaweeds, 16% brown seaweeds, and 8% seagrass (Table 2). The present study showed a high number of identified marine macrophytes relative to that found in some studies in the Philippines. Trono and Saraya (1987), and Baleta and Nalleb (2016) identified 40 seaweeds species in Bolinao, Pangasinan, and 31 seaweed species in Sta. Ana, Cagayan, respectively, in Northern Luzon. Mendoza and Soliman (2013) identified 55 seaweed species in Lagonoy Gulf, Bicol, southeastern Luzon. In addition, Hurtado-Ponce et al. (2006), and Fajardo et al. (2016) identified 45 marine macrophyte species in Mararison Island, Culasi, Antique

**Table 1.** The six indices that represent the surface area covered by seaweed or seagrass species within the small square of the quadrat and their corresponding “multiplier” values for conversion into cover.

Index	Degree of seaweed or seagrass cover in a small square of the quadrat	Multiplier
6	Covering 95%–100% of the substratum surface	4.0
5	Covering 50%–100% of the substratum surface	3.0
4	Covering 25%–50% of the substratum surface	1.5
3	Covering 12.5%–25% of substratum surface	0.75
2	Covering 6.25%–12.5% of substratum surface	0.375
1	Covering <6.25% of substratum surface	0.1875

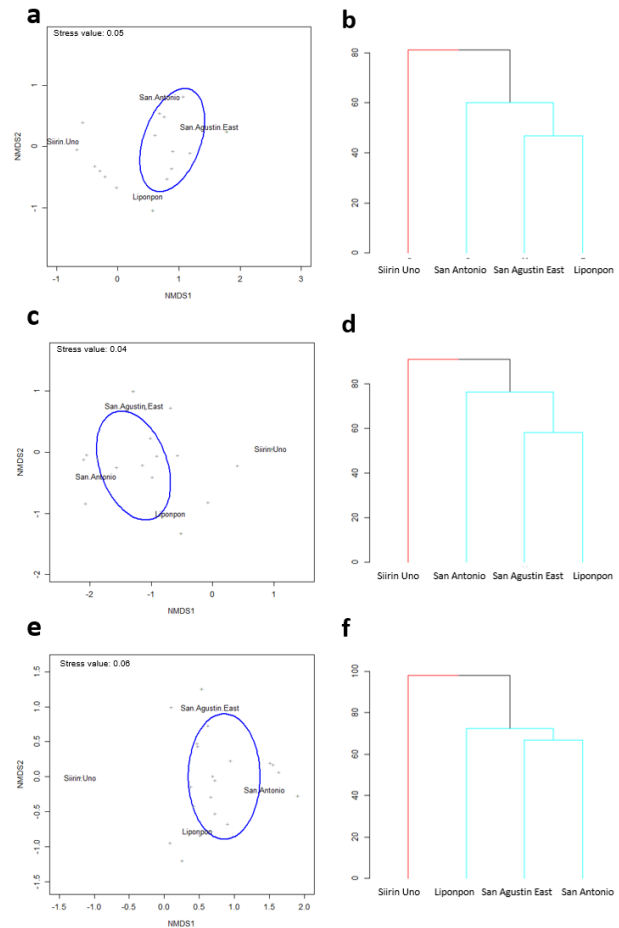
in the Visayas and 31 marine macrophyte species in Claver, Surigao Del Norte in Mindanao, respectively.

The diversity index was high in Siirin Uno and San Agustin East ( $H = 2.01$  and  $2.02$ , respectively) compared with that in San Antonio and Liponpon ( $H = 1.76$  and  $1.69$ , respectively). Overall, the island has low to moderate marine macrophyte diversity ( $H = 1.87$ ) (Table 3). Similarly, Kepel et al. (2019) showed that diversity index ranging from  $H = 2.24$ – $2.61$  constitutes moderate diversity as observed on the seaweed community in North Sulawesi, Indonesia. In addition, Fajardo et al. (2016) showed that the diversity indices of the marine macrophytes in Surigao Del Norte ranged from  $H = 1.07$ – $2.4$  indicating a higher index observed in suitable sites for seaweeds and seagrass. Mendoza and Soliman (2013) showed similar diversity indices indicating that higher index observed in sites exposed to strong waves and currents with low in embayment. Although a high number of marine macrophytes were identified in the present study, a low to moderate diversity index was obtained, which may be due to the low evenness ( $E_H = 0.46$ ) observed especially in seagrass-dominated site and patchy distribution of some marine macrophytes.

### Temporal variation in biodiversity

For all sampling periods, San Agustin East, San Antonio, and Liponpon were significantly similar based on their marine macrophyte composition (Fig. 2). The dominant marine macrophyte species in each site varied across sampling period except for Siirin Uno (Table 4). Species contribution in all sites was generally highest in summer.

During summer, a total of 42 marine macrophyte species were identified, comprising 38 seaweed species and 4 seagrass species. Siirin Uno showed the highest number of species (27 species), followed by Liponpon (16 species), San Agustin East (15 species), and San Antonio (8 species). The NMDS



**Figure 2.** Non-Metric Multidimensional Scaling Analysis (a, c, e) and Similarity Profile Analysis (b, d, f) on the seagrass and seaweed cover among survey sites (San Agustin East, San Antonio, Liponpon, and Siirin Uno) during summer (a, b), southwest monsoon (c, d), and northeast monsoon (e, f). Points denote species and ellipses indicate clustering of similar groups in the NMDS plots. Clusters with the same color are not significantly different (b, d, f).

ordination of macrophyte cover showed the separation of Siirin Uno from San Agustin East, San Antonio, and Liponpon (Fig. 2a). Furthermore, SIMPROF analysis showed two significant clusters for macrophyte cover. One cluster comprise San Agustin East, San Antonio, and Liponpon, and the other cluster comprise Siirin Uno (Fig. 2b). Results of the SIMPER analysis showed that *Halodule pinifolia*, *Cymodocea rotundata*, *Caulerpa verticillata* J. Agardh, *Thalassia hemprichii*, and *Padina* sp. contributed more than 70% of the dissimilarity between Siirin Uno and the other sites (Table 5). The seaweed *Padina* sp. was dominant in San Agustin East, San Antonio, and Liponpon during this period. The dominant species in Siirin Uno were the seagrasses *H. pinifolia* and *C. rotundata* and the green seaweed *C. verticillata*.

**Table 2.** List of seaweed (green, red, and brown) and seagrass species with their corresponding total cover assessed in the four coastal areas in Verde Island, namely, Siirin Uno, San Agustín East, San Antonio, and Liponpon during the summer, southwest monsoon (SW), and northeast monsoon (NE) (total cover is the summation of all cover data from all transect).

Species		Siirin Uno			San Agustín East			San Antonio			Liponpon		
		Summer	SW	NE	Summer	SW	NE	Summer	SW	NE	Summer	SW	NE
Green Seaweeds													
1	<i>Acetabularia major</i> C. Martens	2.3								1.7	3.0	0.8	
2	<i>Acetabularia</i> sp. 1			0.4			0.4						
3	<i>Acetabularia</i> sp. 2		0.8									0.8	
4	<i>Anadyomene plicata</i> C. Agardh		1.5										
5	<i>Boergesenia forbesii</i> (Harvey) Feldman					0.4	0.2		0.8	1.5	0.2		
6	<i>Boodlea composita</i> (Harvey) F. Brand			18.0									
7	<i>Bornetella nitida</i> Munier-Chalmas ex Sonder	14.3	4.7										
8	<i>Bornetella sphaerica</i> (Zanardini) Solms-Laubach	8.6	37.1	1.7							2.1	0.4	
9	<i>Caulerpa serrulata</i> (Forsskål) J. Agardh						0.8			3.0			
10	<i>Caulerpa sertularioides</i> (S.G. Gmelin) M. Howe	27.8	0.4								0.8		
11	<i>Caulerpa verticillata</i> J. Agardh	404.3	703.1	523.5									
12	<i>Codium arabicum</i> Kützinger				18.0						4.5		
13	<i>Codium edule</i> P.C. Silva					0.8							
14	<i>Dictyosphaeria cavernosa</i> (Forsskål) Borgesen	18.0	1.1	4.1				0.4					
15	<i>Dictyosphaeria verslynsii</i> Weber Bosse			0.4						1.9			0.8
16	<i>Halimeda incrassata</i> (J. Ellis) J.V. Lamouroux		12.4	2.6		1.9	2.6		1.5	6.0		12.8	
17	<i>Halimeda opuntia</i> (Linnaeus) J.V. Lamouroux					2.3	14.6				1.5	3.8	2.3
18	<i>Halimeda</i> sp.				10.1							1.5	
19	<i>Neomeris annulata</i> Dickie	1.1	0.4	0.4	0.2	4.7	10.3	3.9	2.3	6.8	2.1	6.0	2.4
20	<i>Udotea orientalis</i> A. Gepp & E.S. Gepp	21.4	10.9	9.2									4.1
21	<i>Ulva clathrata</i> (Roth) C. Agardh	13.5	2.3									6.0	
22	<i>Ulva intestinalis</i> Linnaeus	3.0	3.0	1.5									
23	<i>Ulva lactuca</i> Linnaeus												
24	<i>Ulva reticulata</i> Forsskål		0.4										
25	<i>Valonia aegagropila</i> C. Agardh									1.5			
26	<i>Valonia</i> sp.				4.5								
Brown Seaweeds													
27	<i>Dictyota cervicornis</i> Kützinger	14.6	36.0										
28	<i>Dictyota divaricata</i> (J. Agardh) J. Agardh		91.5										
29	<i>Dictyota</i> sp.				0.8						1.5		
30	<i>Ectocarpus</i> sp.	7.5	44.3										
31	<i>Hormophysa cuneiformis</i> (J.F. Gmelin) P.C. Silva									1.5			
32	<i>Hydroclathrus clathratus</i> (C. Agardh) M. Howe		19.5										
33	<i>Padina</i> sp.	73.9	206.7	2.3	226.3	34.5	0.8	87.9		0.2	119.8	0.6	



Cont'd Table 2. List of seaweed (green, red, and brown) and seagrass species with their corresponding total cover assessed in the four coastal areas in Verde Island.

	Species	Siirin Uno			San Agustin East			San Antonio			Liponpon		
		Summer	SW	NE	Summer	SW	NE	Summer	SW	NE	Summer	SW	NE
34	<i>Sargassum cristaeifolium</i> C. Agardh	29.3			97.5			6.8					
35	<i>Sargassum</i> sp.	25.5	7.5		127.9	6.4		4.5					
36	<i>Turbinaria ornata</i> (Turner) J. Agardh				53.3	4.1	2.3	30.4					
37	<i>Acanthopora spicifera</i> (M. Vahl) Borgesen	10.5		15.8									
38	<i>Actinotrichia fragilis</i> (Forskål) Borgesen				17.8	10.1	3.0	18.4	14.4	13.5	2.3		
39	<i>Amphiroa foliacea</i> J.V. Lamouroux			3.0	10.5	19.1	21.0			1.5	3.4		
40	<i>Amphiroa fragilissima</i> (Linnaeus) J.V. Lamouroux	1.5	0.8			3.0				3.0	11.3	1.5	
41	<i>Ceratodictyon spongiosum</i> Zanardini				3.8	23.3	3.0						
42	<i>Claudea</i> sp.						12.0					2.3	
43	<i>Galaxaura subverticillata</i> Kjellman					1.5			4.5	0.8		3.0	
44	<i>Gracilaria salicornia</i> (C. Agardh) E.Y. Dawson	0.8	6.0	9.4									
45	<i>Gracilaria</i> sp.					0.8	0.8						
46	<i>Gracilaria textorii</i> (Suringar) Hariot			3.0									
47	<i>Halymenia durvillei</i> Bory de Saint Vincent				3.0								
48	<i>Hydroponia edulis</i> (S.G.Gmelin) Gurgel & Fredericq	9.8	3.8	101.3									
49	<i>Hydroponia euchematooides</i> (Harvey) Gurgel & Fredericq			1.1									
50	<i>Hypnea cervicornis</i> J. Agardh	0.4	1.5										
51	<i>Laurencia flexilis</i> Setchell			3.0			0.4			0.8	1.5		
52	<i>Laurencia papillosa</i> (C. Agardh) Greville	6.0	1.5	4.5							1.3		
53	<i>Liagora farinosa</i> J.V. Lamouroux		1.5										
54	<i>Portiera hornemannii</i> (Lyngbye) P.C. Silva			0.8	2.3		3.0		6.0	3.0	2.6	3.8	
55	<i>Rhodomenia</i> sp.											1.5	
56	<i>Spyridia filamentosa</i> (Wulfen) Harvey	2.3											
57	<i>Tolypocladia glomerulata</i> (C. Agardh) F. Schmitz	1.5		1.5									
58	<i>Tricleocarpa fragilis</i> (Linnaeus) Huisman & R.A. Townsend			0.8	32.8	11.6	27.0	1.3	9.4	7.5	13.5	4.5	
Seagrass													
59	<i>Cymodocea rotundata</i> Ascherson & Schweinfurth	422.3	472.9	430.5									
60	<i>Halodule pinifolia</i> (Miki) Hartog	446.6	399.8	295.5									
61	<i>Halophila decipiens</i> Ostenfeld		37.5	6.8									
62	<i>Halophila ovalis</i> (R. Brown) J.D. Hooker	61.5	122.3	43.5									
63	<i>Thalassia hemphricii</i> (Ehrenberg) Ascherson	240.4	186.0	270.8									

During the southwest monsoon, a total of 44 marine macrophyte species were identified, comprising 39 seaweed species and 5 seagrass species. Siirin Uno showed the highest number of species (30 species), followed by San Agustin East (15 species), Liponpon (14 species), and San Antonio (7 species). The species composition during the southwest monsoon was similar to that observed during the summer. The NMDS ordinations of macrophyte cover data showed the separation of Siirin Uno from San Agustin East, San Antonio, and Liponpon (Fig. 2c). Similarly, SIMPROF analysis showed two significant clusters, grouping San Agustin East, San Antonio, and Liponpon together and separately from Siirin Uno (Fig. 2d). Results of the SIMPER analysis showed that *Caulerpa verticillata*, together with the seagrass species, primarily account for  $\geq 70\%$  of the dissimilarity between Siirin Uno and the other sites. For some sites compared, such as Siirin Uno and San Antonio, *Padina* sp. was also found to contribute to the dissimilarity. During this sampling period, *Padina* sp. was not observed in San Antonio. In terms of dominant species, *Padina* sp. was found to be dominant in San Agustin and Liponpon. The red seaweeds *Actinotrichia fragilis* (Forsskål) Børgesen and *Portieria hornemannii* (Lyngbye) P.C. Silva were dominant in San Antonio. The seagrasses *Cymodocea rotundata* and *Halodule pinifolia* and green seaweed *Caulerpa verticillata* were dominant in Siirin Uno.

During the northeast monsoon, a total of 43 marine macrophyte species were identified, comprising 38 seaweed species and 5 seagrass species. Siirin Uno showed the highest number of species (27 species), followed by San Agustin East and San Antonio (both with 16 species) and Liponpon (14 species). The macrophyte species observed during the northeast monsoon was similar to that during summer and southwest monsoon season. Similar results for ordination and clustering were observed during the northeast monsoon (Fig. 2e and 2f, respectively). Similar to the southwest monsoon, *Caulerpa verticillata* and the seagrasses in Siirin Uno mostly contributed ( $\geq 70\%$  contribution) to the high dissimilarity between Siirin Uno and the other sites as shown by the SIMPER analysis. *Tricleocarpa fragilis* (Linn.) Huisman & R.A. Townsend was the dominant species in San Agustin, San Antonio, and Liponpon. The other dominant marine macrophytes were *Amphiroa*, *Halimeda*, *Neomeris*, and *Ulva*. The dominant species in Siirin Uno were the seagrass *Cymodocea rotundata* and green seaweed *Caulerpa verticillata*.

In addition, the NMDS ordination and SIMPROF analysis of macrophyte cover across sampling periods showed slight to no separation during summer, southwest and northeast for Siirin Uno and Liponpon (Figs. 3 and 4), indicating that macrophyte cover was not influenced by changes in monsoon in these areas.

Macrophyte cover during summer was dissimilar to that observed during the monsoons for San Agustin East and San Antonio, which may be due to these sites being more exposed to monsoon.

Siirin Uno was always shown to be significantly separated from the other three sites and Siirin Uno was also the only site dominated by seagrasses. It is therefore important to examine further if the separation was mainly due to the dominance of seagrasses. Hence seagrasses data were removed so that analysis on the diversity pattern of only the seaweed species reported from the sites could be done, in comparison with that of the other three sites. Results of the NMDS ordination showed a similar pattern to that found when sites were compared in terms of both seaweed and seagrass (Supplementary Fig. S2a, c, e), and the same significant clusterings were also observed (Supplementary Fig. S2b, d, f). Siirin Uno still separated from the other sites possibly because of the high cover of the green seaweed *C. verticillata*.

Differences in the dominant species across sampling period were pronounced in seaweed-dominated sites in San Agustin East, San Antonio, and Liponpon. The summer-dominant species *Padina* sp. showed decreasing cover towards the northeast monsoon. Its fragile and broad thallus morphology allows it to be easily dislodged by mechanical forces (i.e., strong wind and water movement) during monsoon seasons. Similarly, Mendoza and Soliman (2013) observed seaweeds with fragile and broad thalli, such as *Padina*, *Dictyota*, and *Ulva*, were not present during monsoons and hypothesized that this species might be dislodged from strong wind and heavy rain. On the other hand, the dominant seaweed species during the two monsoons in these sites, *Amphiroa foliacea* Lamouroux, *Ceratodictyon spongiosum* Zanardini, *Neomeris annulata* Dickie, and *Udotea orientalis* Gepp & Gepp, were mostly small-sized (1-10 cm), exhibit a prostrate habit, or have calcified thalli, which enables these seaweeds to withstand mechanical stresses. Littler and Littler (1980) showed that seaweed species having higher structure tissues such as *Corallina officinalis* Linnaeus, *Pelvetia fastigiata* (J. Agardh) De Toni [now known as *Silvetia compressa* (J. Agardh) Serrão, T.O. Cho, S.M. Boo & Brawley], and *Gelidium* have higher resistance to physical stresses. By contrast, Siirin Uno exhibited a more stable macrophyte community, given the presence of dominant seagrass species all year round such as *Cymodocea rotundata* and *Halodule pinifolia*. Marba et al. (2004) explained that the growth rates of seagrass rhizomes are generally slow, varying from a few cm per year for *Posidonia oceanica* (Linn.) Delile to more than 2 m per year in *Cymodocea nodosa* (Ucria) Ascherson and *Zostera marina* Linn. By contrast, the majority of seaweeds are short-lived or ephemeral and have short life

histories compared with seagrasses (Fortes et al., 2016). Furthermore, Siirin Uno appeared to be more sheltered to monsoon winds than the other sites, possibly protecting the macrophyte vegetation from mechanical stress due to strong winds and water movement.

*Padina* sp. was predominant in Liponpon, San Antonio, and San Agustin East. It also registered a high percent cover in Siirin Uno relative to other macroalgae during the southwest monsoon. The presence of *Padina* sp., as well as its variability in cover, might be indicative of anthropogenic nutrient loading from domestic and agricultural runoff. All sites were near populated areas with poor sewage system, and a few backyard pig pens were observed in San Agustin East, San Antonio, and Liponpon. Fresh and dried biomass of *Padina* have high adsorbing potential for various pollutants (Ansari et al., 2019). *Padina* has also been shown to be a good indicator of anthropogenic nitrogen input in reefs (Umezawa et al., 2002; Mwaura et al., 2017). Differential physiological responses to nutrient supply and capacity for high and long-lasting surge uptake have also been observed in *Padina* (Barrow et al., 2015). They showed similar high nutrient uptake for *Padina* sp. collected from eutrophic and clean waters, which may reflect optimization of nutrient uptake to adapt to their ambient environment. In addition, the observed cover decline in *Padina* sp. during northeast monsoon could be due to the lower water temperatures, which might not be favorable for their growth. Although *Padina* sp. is considered a perennial species, Benita et al. (2018) showed that the thallus may detach during winter. Only the rhizoids or “Vaughaniella” stage, which are filamentous thalli or sporelings, are left. Thus, *Padina* survives until favorable conditions for growth arise again, which is usually observed in spring. *Ulva* spp., which is known to be a bloom-forming species, was present in the area but registered low cover. *Ulva* spp. is known to form blooms under optimum conditions such as increased nutrient input and high light levels, and increased water temperature.

Although the green seaweed *Neomeris annulata* had low cover, it was observed all year round in all of the sites. *N. annulata* produces calcium carbonate (in the form of aragonite) and sesquiterpenes, which confers resistance to grazers, reduced palatability, and thus increased survival (Barnekow et al., 1989; Paul et al., 1993; Meyer & Paul, 1995). Bitar et al. (2005) observed that *N. annulata* exhibits high rates for regeneration during the vegetative phase and high reproduction capability. Furthermore, they observed that the species can survive in dormancy under unfavorable conditions. In addition, Littler and Littler (1980) observed that calcified seaweeds have lower productivity wherein most of their metabolic processes greatly directed in manufacturing structural tissues. See Supplementary

Fig. S3 for the habit photographs of the dominant marine macrophytes in Verde Island, Batangas City.

Seaweeds may be categorized according to the functional-form grouping, wherein thallus morphology is said to have implications to ecophysiological responses (Littler et al., 1983). The majority of the identified and dominant seaweed species (ca. 80%) were coarsely branched (i.e., *Acanthophora spicifera* (Vahl) Børgesen, *Caulerpa sertularioides* (Gmelin) M.A. Howe, *Gracilaria salicornia* (C. Agardh) Dawson, *Laurencia papillosa* (C. Agardh) Greville, and *Liagora farinosa* Lamouroux, *Valonia aegagropila* C. Agardh), thick and leathery (i.e., *Hormophysa cuneiformis* (Gmelin) P.C. Silva, *Sargassum* spp., *Turbinaria ornata* (Turner) J. Agardh, and *Udotea orientalis*), and jointed calcareous (i.e., *Amphiroa foliacea*, *Amphiroa fragilissima* (Linn.) Lamouroux, *Galaxaura subverticillata* Kjellman, *Halimeda incrassata* (J. Ellis) Lamouroux, and *Halimeda opuntia* (Linn.) Lamouroux). The high percentage of these functional forms indicate intermediate and mature communities, which are said to be typical of non-stressful and fairly stable marine environments (Littler & Littler, 1980; Littler et al., 1983). These species are late succession to climax species as exhibited by their slow growth rates, slow colonization of substrates, high resistance to grazing and stress due to non-palatability, and perennial nature (Littler & Littler, 1980). On the other hand, only a few sheet (i.e., *Dictyota* spp., and *Ulva* spp.) and filamentous [i.e., *Spyridia filamentosa* (Wulfen) Harvey] forms were observed. Littler and Littler (1980) observed that sheet and filamentous forms are opportunistic species, exhibiting fast growth rates, rapid colonization of substrates, high susceptibility to grazing due to high palatability, thin and simple thallus construction (i.e., easily torn by waves and sedimentary actions), and ephemeral life histories. In addition, they showed that the prevalence of sheet and filamentous seaweeds were mostly observed in temporally unstable habitat. On the other hand, Connell and Slatyer (1977) introduced the concept that the majority of succession in natural communities never reached a steady-state equilibrium due to major disturbances and stochastic processes thus succession never stops. See Supplementary Fig. S4 for the habit photographs of the representative seaweed species in Verde Island, Batangas City and the corresponding thallus morphology grouping.

In addition, some of the seaweed species were observed only during the northeast monsoon, such as *Amphiroa foliacea*, *Caulerpa serrulata* (Forsskål) J. Agardh, *Claudea* sp., *Dictyosphaeria vershuyssii* Weber Bosse, and *Laurencia flexilis* Setchell. The lower water temperature (ca. 28 °C) during this period may be favorable for the growth of these species. Bischoff-Bäsmann et al. (2006) found that tropical seaweeds



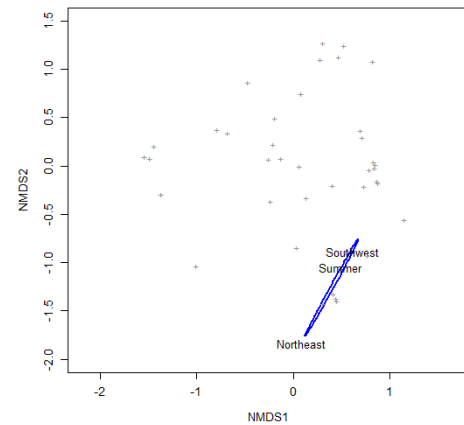
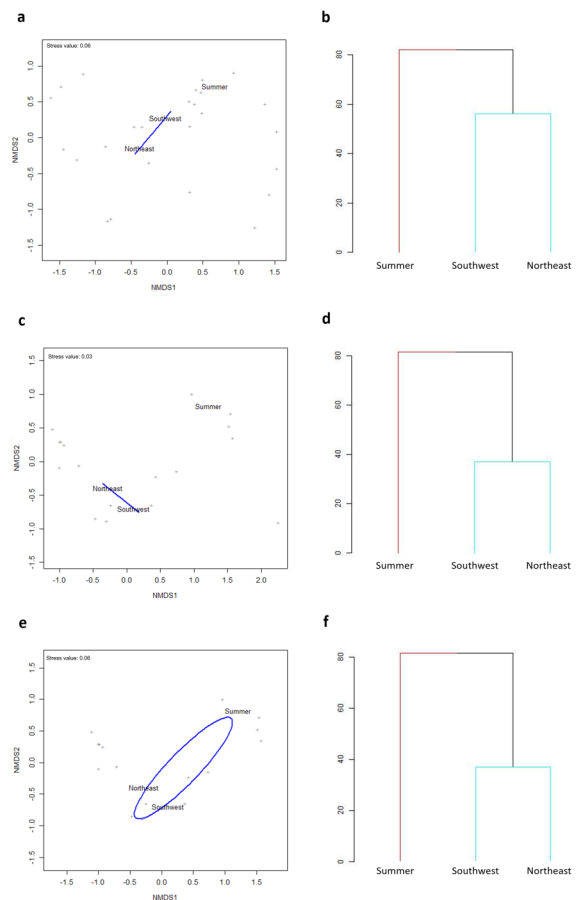
**Table 3.** Diversity indices of the marine macrophytes in each site during the three sampling periods.

Sampling Period	Shannon Diversity Index ( <i>H</i> )			
	Sampling Site			
	Siirin Uno	San Agustin East	San Antonio	Liponpon
Summer	2.08	1.83	1.29	1.24
Southwest Monsoon	2.12	2.13	1.62	1.35
Northeast Monsoon	1.83	2.10	2.37	2.47
<b>Average</b>	2.01	2.02	1.76	1.69

species from Hainan Island showed optimum growth temperature between 25 °C to 30 °C, but some have low survival temperatures, ranging between 7 °C to 16 °C (i.e., *Hypnea*, *Halymenia*, *Gracilaria*, and *Laurencia*). They also found other species that have even lower survival temperatures, ranging between 1 °C to 6 °C (i.e., *Ulva*, *Boergesenia*, *Valonia*, and *Monostroma*). No distinct seaweed species during southwest monsoon were observed probably because of nutrient variability given the fluctuating sedimentation rates due to variability in rain occurrences. Furthermore, measured physicochemical parameters in the present study fluctuated within a close range which might not affect the marine macrophytes composition. Barron (1995) observed that physicochemical factors in the tropical region generally do not undergo major changes, and biotic compositions are largely dependent on biological competition rather than on their ambient physicochemical parameters. Cabrera et al. (2015) found little to no correlation between different physicochemical characteristics and abundance of seaweeds in the coastal area in Lian, Batangas, Philippines.

#### Spatial variation in biodiversity

In general, Siirin Uno had the highest number of species and cover among the sites in all sampling periods. Overall, seaweed-dominated sites have low percent species contribution (1.3% to 8.0% in San Agustin East, 0.5%- to 2.0% in San Antonio and 0.5% to 3.9% in Liponpon), whereas the seagrass-dominated site has high species contribution (23% to 32% in Siirin Uno). The difference in species composition in the sampling sites may be attributed to differences in habitat features such as substrate and topography, which are known to influence marine macrophyte assemblage (Norton et al., 1981; Trono & Saraya, 1987). Seagrass beds are mostly found in soft and sandy substrate and gently sloping, sheltered areas (Short & Coles, 2001; Bekkby et al., 2008). Among the sites, only Siirin Uno exhibit a wide and shallow intertidal flat with mostly sandy to muddy substrate, which is suitable for seagrass growth.

**Figure 3.** Non-Metric Multidimensional Scaling Analysis of seaweed and seagrass cover across sampling periods for Siirin Uno. Points and ellipse indicate species and clustering of similar sampling, respectively.**Figure 4.** Non-Metric Multidimensional Scaling Analysis (a, c, e) and Similarity Profile Analysis (b, d, f) of seagrass and seaweed cover across sampling periods for San Agustin East (a, b), San Antonio (c, d), and Liponpon (e, f). Points and ellipses indicate species and clustering of similar groups in the NMDS plots, respectively. Clusters with the same color are not significantly different (b, d, f).

**Table 4.** Dominant marine macrophyte species constituting 50% or more of the total macrophyte covers in each site during the three sampling periods. Percentage in parenthesis corresponds to the percent species contribution of each species.

Sites	Dominant Species per Sampling Period		
	Summer	Southwest Monsoon	Northwest Monsoon
	(April 2019)	(July 2019)	(December 2019)
Siirin Uno	<i>Halodule pinifolia</i> (24%) <i>Cymodocea rotundata</i> (23%) <i>Caulerpa verticillata</i> (22%)	<i>Caulerpa verticillata</i> (29%) <i>Cymodocea rotundata</i> (20%) <i>Halodule pinifolia</i> (17%)	<i>Caulerpa verticillata</i> (30%) <i>Cymodocea rotundata</i> (25%)
San Agustin East	<i>Padina</i> sp. (37%) <i>Sargassum</i> sp. (21%)	<i>Padina</i> sp. (28%) <i>Ceratodictyon spongiosum</i> (19%) <i>Amphiroa foliacea</i> (15%)	<i>Tricleocarpa fragilis</i> (26%) <i>Amphiroa foliacea</i> (21%) <i>Halimeda opuntia</i> (14%)
San Antonio	<i>Padina</i> sp. (57%)	<i>Actinotrichia fragilis</i> (37%) <i>Portieria hornemannii</i> (15%)	<i>Actinotrichia fragilis</i> (25%) <i>Tricleocarpa fragilis</i> (14%) <i>Neomeris annulata</i> (13%)
Liponpon	<i>Padina</i> sp. (69%)	<i>Padina</i> sp. (66%)	<i>Ulva clathrata</i> (17%) <i>Tricleocarpa fragilis</i> (13%) <i>Udotea orientalis</i> (12%) <i>Portieria hornemannii</i> (11%)

San Antonio, and Liponpon are mostly characterized by a rocky area with patches of sand, as well as some corals and coral rubble. These three sites also exhibit an abrupt slope towards the coral reef area. Hence, macroalgae and not seagrasses thrived in these sites. Typically, diverse seaweeds flourish in rocky areas, which provide stable substrate and microhabitats (Chapman & Chapman, 1973). In the case of the seagrass-dominated area, Siirin Uno, high macroalgal cover was observed primarily because of the rhizophytic seaweed *Caulerpa verticillata* found interspersed with the seagrass. In addition, beyond the seagrass meadow (approximately 25 m to 30 m from the shore) are areas with rocky substrate, where many epilithic seaweeds were observed. Thus, the substrate heterogeneity, along with the comparatively wide and shallow shore, in Siirin Uno may have allowed for higher macroalgal diversity, as well as higher species cover overall, than in other sites. Preliminary studies on marine macrophyte structure in Siirin Uno and Bayanan Uno (located also southwest of Verde Island) showed higher macroalgal diversity in the latter, which also has a relatively wide and gently sloping area but rocky substrate (Vacarizas et al., unpublished).

#### Conservation and protection of Verde Island

Some economically valuable species of macroalgae were recorded, namely, *Portieria hornemannii* and *Halymenia durvillei* Bory de Saint Vincent, which are potential sources of

commercial and natural products (Trono, 1997, 2010; Cordero, 2003; Senthilkumar et al., 2013; Wang et al., 2020). *P. hornemannii* was found in all sites and all sampling periods. *H. durvillei* was found only in San Agustin East during summer. Both species have low cover. Wild stock gathering of these species is not advisable because of the low cover of the natural population. Trono (2010) has developed a technology for mass production of *H. durvillei* in a land-based culture facility, but a low-cost farming technology similar to *Eucheuma* and *Kappaphycus* by vegetative fragmentation could be developed as an alternative. This farming method was observed in areas with few or no natural population of the species. Additionally, *Claudea* sp. was also collected in Verde Island and needs verification. Only two species of this genus have been reported in the Philippines, both of which exhibit limited distribution (Silva et al., 1987; Trono, 1997; Kraft et al., 1999; Ang et al., 2013). Silva et al. (1987) cataloged the distribution of *C. batanensis* Tanaka in Batanes and *C. multifida* Harvey in Luzon: Ilocos Norte, Pangasinan, Batangas, Oriental Mindoro; Visayas: Panay, Aklan, Guimaras, Cebu, Siquijor. Trono (1997) made an additional record of *C. batanensis* in Luzon: Babuyan Island, Cagayan, and Visayas: Nogas Island, Antique while Kraft et al. (1999) in Sorsogon. See supplementary Fig. S5 for the habit photographs of other notable seaweeds species in Verde Island, Batangas City.

**Table 5.** Species contributing to the dissimilarity between sites for each sampling period based on the similarity of percentage (SIMPER) analysis. Species listed are those with  $\geq 70\%$  cumulative contribution (CC%) to the dissimilarity.

Sites compared	Summer		Southwest monsoon		Northeast monsoon	
	Species	CC%	Species	CC%	Species	CC%
Siirin Uno vs. San Agustin East	<i>Halodule pinifolia</i>	0.20	<i>Caulerpa verticillata</i>	0.29	<i>Caulerpa verticillata</i>	0.29
	<i>Cymodocea rotundata</i>	0.39	<i>Cymodocea rotundata</i>	0.48	<i>Cymodocea rotundata</i>	0.52
	<i>Caulerpa verticillata</i>	0.57	<i>Halodule pinifolia</i>	0.64	<i>Halodule pinifolia</i>	0.68
	<i>Thalassia hemprichii</i>	0.68	<i>Thalassia hemprichii</i>	0.72	<i>Thalassia hemprichii</i>	0.83
	<i>Padina</i> sp.	0.75				
Siirin Uno vs. San Antonio	<i>Halodule pinifolia</i>	0.24	<i>Caulerpa verticillata</i>	0.29	<i>Caulerpa verticillata</i>	0.29
	<i>Cymodocea rotundata</i>	0.47	<i>Cymodocea rotundata</i>	0.48	<i>Cymodocea rotundata</i>	0.53
	<i>Caulerpa verticillata</i>	0.69	<i>Halodule pinifolia</i>	0.64	<i>Halodule pinifolia</i>	0.70
	<i>Thalassia hemprichii</i>	0.82	<i>Padina</i> sp.	0.73	<i>Thalassia hemprichii</i>	0.85
Siirin Uno vs. Liponpon	<i>Halodule pinifolia</i>	0.22	<i>Caulerpa verticillata</i>	0.30	<i>Caulerpa verticillata</i>	0.30
	<i>Cymodocea rotundata</i>	0.43	<i>Cymodocea rotundata</i>	0.51	<i>Cymodocea rotundata</i>	0.54
	<i>Caulerpa verticillata</i>	0.64	<i>Halodule pinifolia</i>	0.68	<i>Halodule pinifolia</i>	0.71
	<i>Thalassia hemprichii</i>	0.76	<i>Thalassia hemprichii</i>	0.76		
San Agustin East vs. San Antonio	<i>Padina</i> sp.	0.30	<i>Padina</i> sp.	0.31	<i>Amphiroa foliacea</i>	0.19
	<i>Sargassum</i> sp.	0.56	<i>Ceratodictyon spongiosum</i>	0.51	<i>Tricleocarpa fragilis</i>	0.37
	<i>Sargassum cristaeifolium</i>	0.76	<i>Amphiroa foliacea</i>	0.68	<i>Halimeda opuntia</i>	0.51
			<i>Sargassum</i> sp.	0.74	<i>Claudea</i> sp.	0.63
San Agustin East vs. Liponpon					<i>Actinotrichia fragilis</i>	0.73
	<i>Sargassum</i> sp.	0.30	<i>Padina</i> sp.	0.48	<i>Tricleocarpa fragilis</i>	0.22
	<i>Sargassum cristaeifolium</i>	0.53	<i>Ceratodictyon spongiosum</i>	0.61	<i>Amphiroa foliacea</i>	0.42
	<i>Turbinaria ornata</i>	0.66	<i>Amphiroa foliacea</i>	0.70	<i>Halimeda opuntia</i>	0.54
	<i>Liagora farinosa</i>	0.73			<i>Claudea</i> sp.	0.64
San Antonio vs. Liponpon					<i>Neomeris annulata</i>	0.72
	<i>Padina</i> sp.	0.44	<i>Padina</i> sp.	0.65	<i>Actinotrichia fragilis</i>	0.23
	<i>Liagora farinosa</i>	0.56	<i>Actinotrichia fragilis</i>	0.72	<i>Halimeda incrassata</i>	0.34
	<i>Turbinaria ornata</i>	0.67			<i>Ulva clathrata</i>	0.44
	<i>Tricleocarpa fragilis</i>	0.76			<i>Neomeris annulata</i>	0.52
					<i>Caulerpa serrulata</i>	0.57
					<i>Tricleocarpa fragilis</i>	0.62
					<i>Claudea</i> sp.	0.66
					<i>Galaxaura subverticillata</i>	0.70

## Conclusion and Recommendation

In summary, this study showed differences in marine macrophyte composition among selected coastal areas in Verde Island, Batangas City, Batangas, Philippines. Temporal differences were more pronounced in macroalgae-dominated sites (San Agustin East, San Antonio, and Liponpon) than in the seagrass-dominated site (Siirin Uno). Differences in marine macrophyte composition across sites may be ascribed to habitat differences, specifically substrate and topography and the morphology and ecophysiological profiles of the species. The seagrass-dominated site registered the highest number of species and species cover among the sites. Most of the marine macrophytes recorded characterize stable and mature communities. This study is the first detailed assessment on the seaweed and seagrass communities of Verde Island. Findings from this study will also contribute to a better understanding of the biodiversity of seaweed and seagrass in the VIP. Many notable seaweed species that may be investigated further were recorded in Verde Island. *Padina* sp. was dominant in many of the sites and may be studied as a bioindicator species, given that the sites surveyed may be exposed to domestic and agricultural wastewater runoff. Other seaweed species that were recorded that have been previously identified as potential markers of eutrophication include *Caulerpa verticillata* and *Ulva* sp.; these species have been previously identified to be potentially invasive and form blooms (Lapointe et al., 1994; Largo et al., 2004; Villaluz et al., 2016). In addition, *N. annulata* may be studied as a model species for studies on ocean acidification and climate change. Economically valuable species (*Portieria hornemannii* and *Halymenia durvillei*) with potential for commercial cultivation were also present in the surveyed sites. An uncommon seaweed species, *Claudea* sp., was noted as well and needs further verification. Regular monitoring and expanding area for assessment is thus important for furthering studies on biodiversity and discovery of uncommon seaweed species in the area. Regular monitoring of marine macrophyte composition is recommended and necessary for understanding the status of these ecosystems and developing measures for conservation, sustainable utilization, and management. Other abiotic factors (e.g., light, nutrients, and water motion) and biotic factors (e.g., competition and grazing) should also be assessed to determine influence on the temporal and spatial variation in marine macrophyte abundance and composition in the island. Given that a diverse marine fauna was also often observed in these seagrass and seaweed areas during field surveys, conducting further ecological studies may elucidate and highlight the role of these marine macrophytes, espe-

cially seaweeds, which should be considered in the design of protected areas (Saco, 2016). Monitoring the status of these ecosystems is also important in expanding knowledge on the marine biodiversity of the VIP.

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